THz Imaging with Broadband Thermal Sources

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***Abstract*—We developed a THz imaging system based on a broadband thermal source (at 500 °C) and an asymmetric semiconductor nanochannel, the self-switching nanodiode (SSD), as a room-temperature detector. The maximum resolution was better than 0.5 mm full width at half maximum. The radiation was coupled to the SSD through a microantenna, whose geometry determined the frequency bandwidth of the system. While not as accurate as coherent imaging, the compactness, low-cost, and flexibility make this system attractive for a large range of applications in medical imaging and industrial quality control.**

I. INTRODUCTION

One of the most attractive features of THz radiation is the unique ability to penetrate several materials which are normally opaque in the optical and infrared frequency range. This has led to explore its use in a number of commercial applications, such as stand-off security screening, non-invasive medical and biological imaging, and industrial quality control. While fascinating results are now routinely obtained, the cost a full THz imaging system is often prohibitive, and cannot always be justified in commercial applications.

One of key reasons for such a high cost is the complexity of the THz source and detector. Time-domain spectroscopy –one of the most common THz systems– provides excellent coherent imaging performance, with the ability to fingerprint specific molecules, but requires expensive femtosecond lasers and relatively complex optics. However, such a high resolution in the frequency domain is not always required, and a simple broadband beam if often all is needed to achieve detailed images in the THz domain. Avoiding coherence detection enables more flexibility in the design at system level and simple thermal sources can be effectively used.

Here we report on a compact and cost-effective THz imaging system based on an inexpensive broadband thermal source and an ultrafast nanodiode as a detector.

II. RESULTS

The diagram of our system is shown in Fig. 1(a). Thermal radiation was generated by a calibrated black-body source at a temperature of 500 °C, which radiates a considerable amount of power at THz frequencies. The radiation transmitted through the sample was collected by a parabolic mirror, collimated, and then focused by a second parabolic mirror on the detector. The detector output voltage was read out with a lock-in amplifier and an optical chopper (not shown). The image was formed by moving the detector in a raster scan pattern, using a computer-controlled XY stage. It is important to note that whereas our source was a relatively expensive calibrated radiator, typical in a laboratory setting, an inexpensive hot-plate could be used instead with good results and high thermal emissivity in the infrared if the surface is finished with suitable black paint.

The detector, shown in Fig. 2, is based on the so-called self-switching nanodiode (SSD), an asymmetric nanochannel fabricated by etching two L-shaped trenches into the two-dimensional electron gas (2DEG) in a GaAs/AlGaAs heterostructure. A three-dimensional atomic-force micrograph of an SSD is shown in false colors in Fig. 2(b). As the depletion region in the channel changes with the applied bias, a diode-like characteristic is observed, and detection occurs by rectifying the alternating radiation field into a dc voltage. We recently demonstrated room-temperature operation of SSDs at THz frequencies, and studied their performance in term of responsivity and noise equivalent power [1□3]. We found that the SSD compared favorably with Schottky diodes [2], and the single-step fabrication process provides obvious cost benefit. Details on the semiconductor material used, the fabrication process and the electrical characteristic can be found in our previous works [1□2]. Monte-Carlo simulations of the SSD at THz frequency are discussed in Ref. 4.

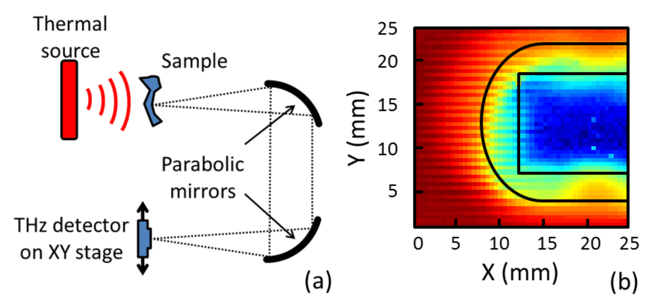

Fig. 1. (a) Diagram of the broadband THz imaging system. The thermal radiation from the black-body source is transmitted through the sample and focused on the self-switching nanodiode detector. (b) The image of a USB memory stick. THz radiation penetrates through the plastic case (yellow area), but is completely stopped by the metal connector (blue area).

The frequency at which the imaging system operates is determined by the antenna bandwidth rather than by the device or the material used. We used a self-complementary log-spiral antenna, shown in Fig. 2(a), with a broad frequency bandwidth of approximately 0.3-5 THz, as this range provides good contrast between different materials, while retaining spatial resolution. The frequency range can however be easily tuned for satisfying specific application requirements by adjusting the antenna geometry. Narrowband operation is also possible using, for example, interdigital dipole antennas or patch-antenna arrays.

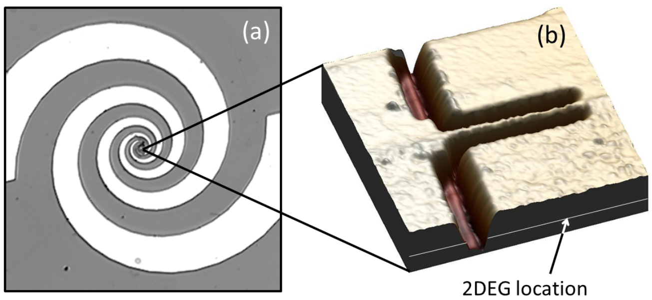

Fig. 2. (a) Micrograph of the self-complementary log-spiral antenna, the estimated bandwidth is 0.3□5 THz. (b) Three-dimensional atomic-force micrograph of an SSD showing the asymmetric nanochannel. The imaging field is 3 µm × 3 µm. The anode and the cathode are located on the right- and left-hand side, respectively, and are connected to the two spiral arm of the antenna.

The imaging operation of the system is demonstrated in Fig. 1(a), which shows the image of a USB memory stick, with its edge shown in the overlay. This type of imaging is quite representative of what would be expected in quality-control applications, for example in defect detection, or in the pharmaceutical industry to monitor the distribution of drugs within tablets. The broadband THz radiation could penetrates the plastic case (yellow area), but was blocked by the metal connector (blue area). The small asymmetry in the image was due to some minor misalignment of the optics.

The spatial resolution of the system was determined by imaging an array of holes drilled through a thin copper plate, and it was better than 0.5 mm full-width at half maximum. The dynamic range depended on the transmission characteristic of the sample, with a maximum of 1500:1 (approximately 32 dB) for an integration time of 100 ms. A longer integration time can improve the dynamic range, but would result in a longer imaging time using a detector with a single pixel.

III. Conclusions

We showed how a compact and cost-effective THz imaging system can be build using thermal source a frequency-selective detector. The frequency bandwidth of the system is determined by the antenna, which can be either broadband or narrowband, according to application requirements. Our current work focuses on the fabrication of a detector array, exploiting the simple fabrication process of the SSD. The use of multi-pixel arrays does not require rastering, resulting in orders of magnitude improvement in imaging time. Moreover, longer integration times can be used for increasing the dynamic range of the system.

Acknowledgement

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